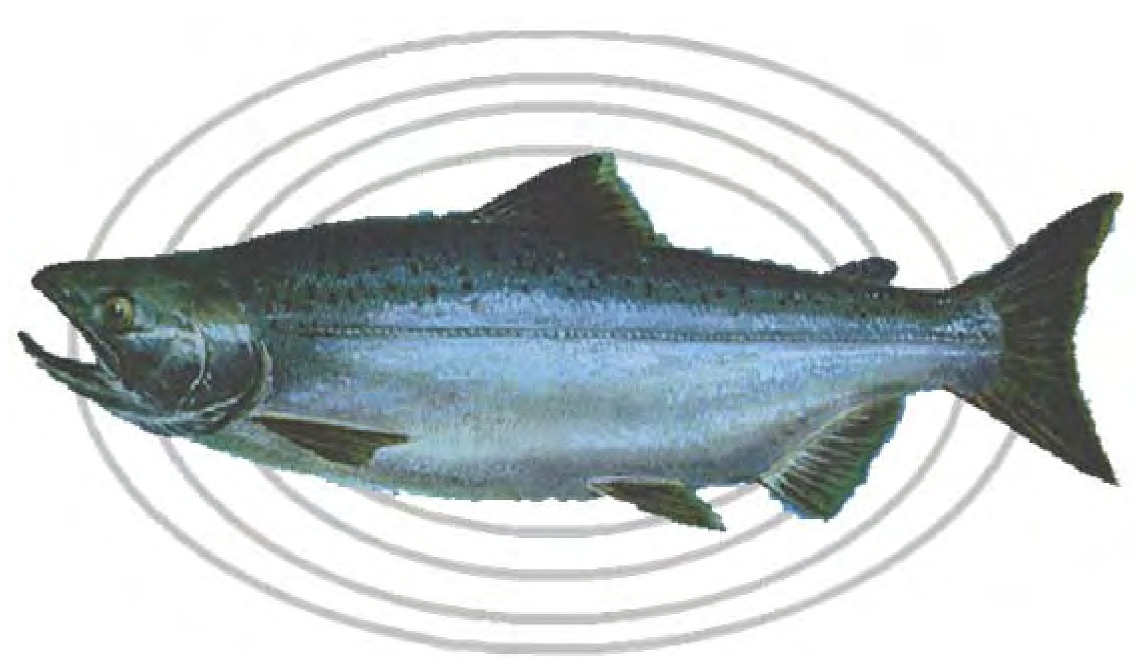
SURVIVAL AND MIGRATORY PATTERNS OF CENTRAL VALLEY JUVENILE SALMONIDS

FINAL REPORT: U-05-SC-047



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Task 1: Management and Administration

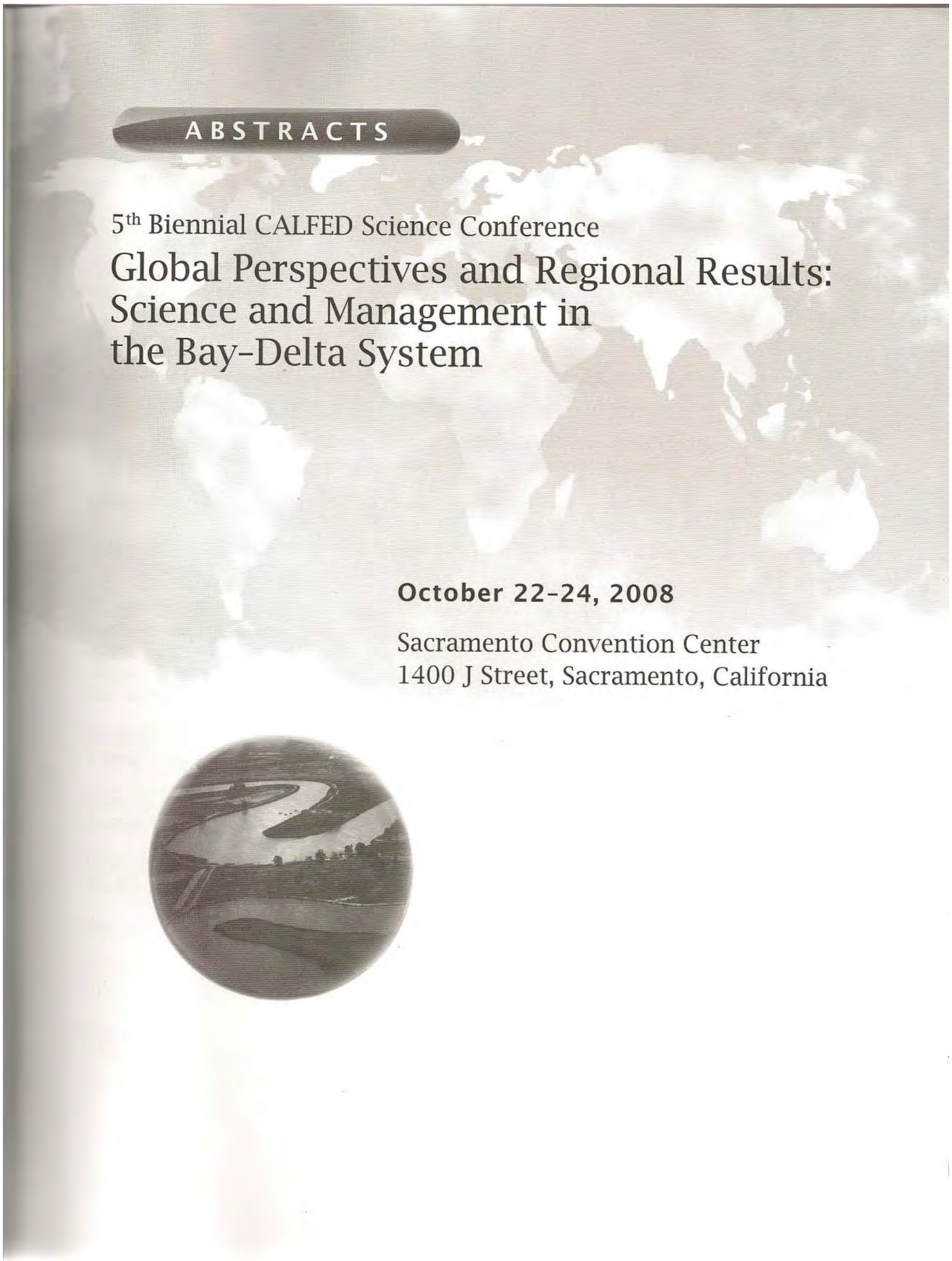
The principle investigator (APK) managed the project. This involved frequent inspection of the work in progress. He worked closely with the co-investigators to coordinate completion of tasks, supervised graduate students, gave scientific presentations, and jointly authored publications. He assembled the semiannual reports, based on reports from the co-principle investigators of the tasks described in this proposal. Finally, APK put together the final report for the research project.

APK made a concerted effort to communicate the results of this study to the scientific community, interest and stakeholder groups, and the public concerned with the health of the salmonid runs in the Central Valley. Posters, describing the planned studies for juvenile Chinook and steelhead, were prepared at the beginning of Year 1 of the grant for the 8th Biennial State of the Estuary Conference, held in October 2007. This meeting is attended by academic and agency scientists, consultants, and the general public. The results of Year 1's studies were reported at the 5th Biennial CALFED Science Conference, which was held during October 2008 (Appendix I).

Graduate student Phil Sandstrom and he organized and held a symposium, entitle "Electronic tagging studies of salmon migration" (Appendix II), during May 2010 at the Bodega Marine Laboratory of UC Davis. This meeting served to publicize the results of our studies and place them in the context of other studies being conducted on the western coast of North America. We invited presentations from scientists, conducting similar studies, from elsewhere in California, Oregon, Washington, and Canada. This meeting was attended by scientists, resource managers, and the interested public. The presenters at this meeting have written scientific articles for a Special Issue of *Environmental Biology of Fishes*. The contributions have been peer-reviewed, and the authors are in the process of making editorial changes to their articles before the publication will be released during 2012. APK and the co-PIs of the contract have written an introduction to the issue, and an abstract and draft of the manuscript are included with this report.

Appendix I

Sandstrom, P.T. and A.P. Klimley. 2008. Migratory movements and success of salmonids. Session, 5th Biennial CALFED Science Conference, Sacramento.



ABSTRACTS

5th Biennial CALFED Science Conference

Global Perspectives and Regional Results: Science and Management in the Bay-Delta System

October 22-24, 2008

Sacramento Convention Center
1400 J Street, Sacramento, California

ORAL ABSTRACTS

Underline denotes presenting author.
*Student Presenter

Oral abstracts are ordered by date, room, and time.

10/22 AM, Rooms 311-315, Plenary Session

10/22 PM, Room 306, Migratory Movements and Success of Salmonids

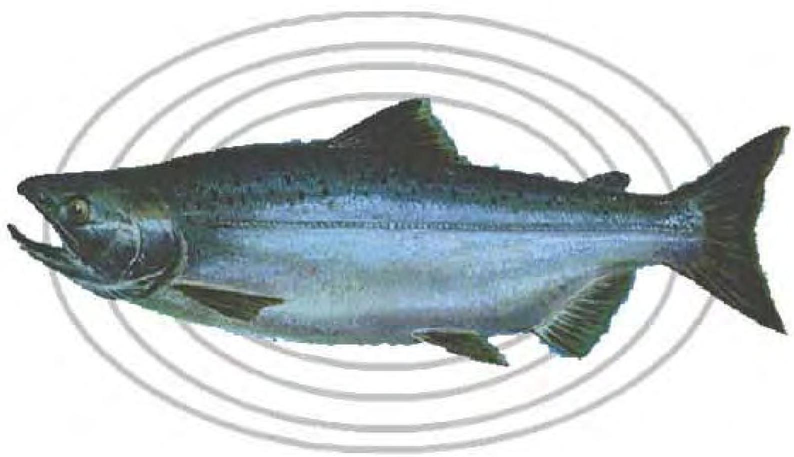
10/22 PM, Room 307, Physical Processes

Appendix II

Sandstrom, P.T. and A.P. Klimley. 2010. Electronic tagging studies of salmon migration. Symposium, Bodega Marine Laboratory, Bodega Bay.

Symposium

Electronic Tagging Studies of Salmon Migration



Conference at

Bodega Marine Laboratory

Bodega Bay, California

20-21 May 2010

Acknowledgements

We would like to express our gratitude to the CALFED Science Program, now the Delta Science Program, for providing the funding that has made this conference possible. The following consulting firms, Cramer Fish Sciences, ECORP Consulting Inc., and ENVIRON INTERNATIONAL have made gracious donations to make possible our wine and beer mixer after the scientific sessions on Thursday.

Introduction

Tracking technology has held hostage our knowledge of the timing and extent of migration of salmonids. For example, the movements of salmonids were first determined by affixing plastic tags on the dorsum or dorsal fin with instructions to convey the date and location of capture to the releasers of the fish. These studies provided a start and end point to a fish's collective movement over a defined period, but were unable to provide information on the path taken by the fish between the two points. These "mark and recapture" studies almost invariably underestimated the extent of the movement of the fish. At least, a fish caught at the same locality of tagging might be assumed to be resident over the period between tagging and recapture, when it could have moved a considerable distance away before returning to that site. These studies, involving the marking of thousands of fish, were often conducted in conjunction with commercial fisheries, and the captured tagged fish were usually part of the annual harvest. Hence, the migration of the fish was interrupted at some point, with the loss of any information on the further movement of the individual. Furthermore, removal of the tagged individual from its environment precluded a single fish returning repeatedly to a single site, a behavioral phenomenon called "homing".

Recent advances in electronic tagging technology have expanded the horizon of our knowledge about salmon migration. Coded, ultrasonic beacons have been place within salmon smolts, and reach-specific rates of movement and survival are now being recorded by tag detecting monitors. The automated data loggers are placed along multiple reaches, each with different patterns of flow and river bed and bank geomorphologies at constant spatial intervals along the mainstreams of rivers, throughout the many interconnected waterways of deltas, and across sections of the bays. Archival tags, which determine the geographic coordinates of fish based on light measurement, have recently been miniaturized sufficiently to be placed on steelhead, an interoparous species that makes yearly migrations out of the watershed and into the ocean before returning to its spawning site on successive years. These tags, and their stored archives of positions, can be retrieved from a significant fraction of the migrating steelhead.

It is the purpose of this symposium to convince scientists worldwide of the value using these new tagging technologies to elucidate the migrations of salmonids. The results of many studies, although still in their infancy, are presented in this volume. These are just the first rewards for the technological effort. The symposium will begin with talks devoted to describing the technologies and their limitations. A second section of the symposium will be devoted to talks revealing what we have learned about the behavior and physiology of salmonids from these tagging studies. Thirdly, talks will be given on the mathematical analyses used to determine rates of survival and detection probability of detection arrays. A final section will be devoted to articles illustrating the extent of movement of salmonids both in the watershed and the open ocean. Recent advances in electronic tagging have considerably augmented the information available on salmonids. The talks given in this session will lead to manuscripts, which will be collected and published in a Special Issue of *Environmental Biology of Fishes*.

MAY 20, 2010

Tagging Technology: Limitations and Capabilities

Chair: Pete Klimley

9:00 **Welcome, Role of CALFED/Other agencies in collaborative telemetry studies**
Peter Klimley, BruceMacFarlane, Phil Sandstrom

9:20 **Ultrasonic and Radio Telemetry of Salmonids Past to Present: A Historical Review of Tagging Practices and Technologies**
Peter Klimley, University of California Davis (Davis, CA)

9:40 **Vemco Technologies**
Dale Webber, Amirix/Vemco (Hallifax, NS, Canada)

10:00 **Lessons Learned from the Columbia River Basin**
John Ferguson, National Marine Fisheries Service (Seattle, WA)

10:20 **BREAK**

10:40 Christa Woodley

11:00 **Mobile Receivers: Releasing the Mooring to See Where Fish Go**
Sean Hayes, National Marine Fisheries Service (Santa Cruz, CA)

11:20 **Benchmark and Field Tests of the Range of Automated Monitors for Three Sizes of Ultrasonic Transmitters**
Gabriel Singer, University of California Davis (Davis, CA)

11:40 **Monitor Detection Efficiency and Tidal Currents**
Arnold Ammann, National Marine Fisheries Service (Santa Cruz, CA)

12:00 **LUNCH**

Behavior and Physiology

Chair: Bruce MacFarlane

13:00 **Growth and Swimming Performance of Chinook Salmon and Steelhead Yearlings Implanted with Acoustic Transmitters**
Arnold Ammann, National Marine Fisheries Service (Santa Cruz, CA)

13:20 **Tag Size Effects on Fish While Migrating**
Michael Melnychuk, University of Washington (Seattle, WA)

13:40 **Differential Use of Repaired Banks and Naturalized Sites by Outmigrating Juvenile Hatchery Steelhead in the Sacramento River, California**
Peter Nelson, H.T. Harvey (Arcata, CA)

14:00 **Fine-scale Movement, Habitat Associations and Survival of Wild *Oncorhynchus mykiss* of the Mokelumne River, CA, from Acoustic Telemetry in Standardized Transects**
Walter Heady, University of California Santa Cruz (Santa Cruz, CA)

14:20 **Tracking Efficiency of Coded Acoustic Tags Based on Pulse Rate, Habitat Type and Flow Regimes in the Lower Yuba River**
Johnathan Nelson, California Department of Fish & Game (Rancho Cordova, CA)

14:40 **An Evaluation of Mobile Tracking Efficiency Using Coded Acoustic Tags in the Lower Yuba River**
Roger Bloom, California Department of Fish & Game (Rancho Cordova, CA)

15:00 **BREAK**

15:20 **The Hydrophone Data Repository an Online Tag Detection Sharing and Research Coordination solution**
Jennifer Scheurell, Sound Data Management (Seattle, WA)

15:40 **Post-spawn Migration of Steelhead Kelts in the Sacramento River Basin of California**
Robert Null, U.S. Fish & Wildlife Service (Red Bluff, CA)

16:00 **Using Radio Telemetry to Inform Rescue Strategies for Central Valley Spring-run Chinook Salmon**
Chris Mosser, University of California Davis (Davis, CA)

16:20 **Fish Passage Studies at the Suisun Marsh Salinity Control Gates in Montezuma Slough**
Robert Vincik, California Department of Fish & Game (Rancho Cordova, CA)

16:40 **Using the Eulerian Lagrangian Agent Method (ELAM) for Forecasting Fish Movement in Response to Levee Repair on the Sacramento River**
David Smith, U.S. Army Corps of Engineers (Vicksburg, MS)

17:00 **Fish Distribution and Entrainment Estimates from 3-D Particle Tracking with Vertical Migration Behavior**
Ed Gross, Bay Modeling (Oakland, CA)

MAY 21, 2010

Survival Estimates and Detection Probabilities

Chair: Cyril Michel

8:00 **Migration of Late-fall Chinook and Steelhead Smolts Relative to Dredge Removal and Disposal Sites in San Francisco Bay**
Alex Hearn, University of California Davis (Davis, CA)

8:20 **Using Acoustic Tags to Understand the Potential Impact of Exports on Survival through the Delta**
Patricia Brandes, U.S. Fish & Wildlife Service (Stockton, CA)

8:40 **Effects of Tides, River Flow, and Gate Operations on Entrainment of Juvenile Chinook Salmon into the Interior Sacramento-San Joaquin Delta**
Russell Perry, University of Washington (Seattle, WA)

9:00 **Movement and Mortality Patterns of Central Valley Juvenile Late-fall Run Chinook Salmon (*Oncorhynchus tshawytscha*) and the Environmental Factors that Shape Them**
Cyril Michel, National Marine Fisheries Service (Santa Cruz, CA)

9:20 **Survival of Juvenile, Late-fall Chinook Salmon Using Different Migration Routes to Negotiate the Sacramento-San Joaquin River Delta**
Russell Perry, University of Washington (Seattle, WA)

9:40 **Steelhead Pre-screen Loss in Clifton Court Forebay**
Kevin Clark, Department of Water Resources (Sacramento, CA)

10:00 **Sacramento River Steelhead (*O. mykiss*): Comparing Movement and Survival of Hatchery and Natural Smolts**
Philip Sandstrom, University of California Davis (Davis, CA)

10:20 **BREAK**

10:40 **Adjusting Survival Estimates to Account for Premature Tag Failure: Application to the VAMP 2008 Acoustic Telemetry Study**
Chris Holbrook, U.S. Geologic Survey (Cook, WA)

11:00 **Vernalis Adaptive Management Plan (VAMP) 2009 Tagging Study: Salmon vs. Predators**
Rebecca Buchanan, University of Washington (Seattle, WA)

11:20 **Testing of an Acoustic/Bubble/Strobe Light Barrier to Improve Escapement of**

Chinook Smolts in California's Sacramento-San Joaquin Delta
Mark Bowen, U.S. Geological Survey (Denver, CO)

11:40 **2010 VAMP Study Plan and Related Challenges**
Patricia Brandes, U.S. Fish & Wildlife Service (Stockton, CA)

12:00 **Use of Telemetry to Evaluate Chinook Salmon Smolt Migration and Mortality in California's Sacramento – San Joaquin Delta**
Dave Vogel, Natural Resource Scientists, Inc. (Red Bluff, CA)

12:20 **LUNCH**

Movements and Migration

Chair: Phil Sandstrom

13:20 **Migration Timing, Rate, Pathways and Survival of Central Valley Steelhead through the Sacramento-San Joaquin Delta and Bays: A Case Study on the Mokelumne River**
Casey DelReal, East Bay Municipal Utilities District (Lodi, CA)

13:40 **A Fork in the Road: Using a VPS Array to Determine the Tracks of Salmon Smolts at the Junction between the Mainstem Sacramento River and the Delta Cross Channel**
Anna Stephenson, University of California Davis (Davis, CA)

14:00 **Movement Patterns of *O. mykiss* in the American River**
Erin Collins, California Department of Fish & Game (Sacramento, CA)

14:20 **Seasonal Movement Patterns of Feather River Natural and Hatchery Origin *O. mykiss***
Ryon Kurth, Department of Water Resources (Oroville, CA)

14:40 **BREAK**

15:00 **Acoustic Tracking of Wild Steelhead Smolts on the Alsea River, Oregon**
Camille Leblanc, Oregon State University (Corvallis, OR)

15:20 **Spatio-temporal Migration Patterns of Salmon Smolts Downstream and through the Strait of Georgia, B.C.**
Michael Melnychuk, University of Washington (Seattle, CA)

15:40 **Estuarine and Coastal Marine Behavior of Staging Adult Chinook Salmon Returning to the Klamath River Basin**
Josh Strange, University of Washington (Seattle, CA)

16:00 **Coho Salmon Residence Time and Habitat Use in Humboldt Bay, CA,: An Acoustic Telemetry Study**
Bill Pinnix, U. S. Fish & Wildlife Service (Arcata, CA)

16:20 **Klamath River Radio-Tagged Juvenile Coho and Their Response to Environmental Variables**
John Beeman, U. S. Geological Survey (Cook, WA)

16:40 **Movements and Behavior of Juvenile Coho Salmon on the Trinity River**
Robert Chase, Bureau of Reclamation (Red Bluff, CA)

17:00 **BREAKOUT SESSION:** New areas research: Questions in the Rivers and Tributaries, Estuaries, and off the Coast of California. Future potential of California Fish Tracking Consortium.

Abstracts from Scientific Talks and Posters

(1) Klimley, A.P. 2010. An historical review of tracking anadromous salmonids. Talk, Electronic Tagging Studies of Salmon Migration Symposium, Bodega Bay.

An historical review of tracking anadromous salmonids

Juvenile salmon were first tracked in rivers carrying radio frequency (RF) transmitters, which were either implanted within the stomach or peritoneal cavity. An advantage of the RF tags was its small size, which permitted its use with smolts < 130 mm TL, and a signal detectable over tens of meters using a hand-held directional antenna; a disadvantage was its external wire antenna that must pass either through the esophagus or body wall. High rates of mortality were recorded in these studies, which may involve an inability to feed due to mouth blockage and a high risk of predation due to the drag of the antenna in water. One method of avoiding these pitfalls is coiling the antenna and coating it with epoxy. However, this reduces the range of transmission. Adults salmon were first tracked in the estuary using ultrasonic frequency (UF) transmitters. A disadvantage of the UF transmitters were there larger size needed to accommodate a larger battery and a ceramic ring, a piezoelectric transducer (PZT), needed for signal transmission. Later studies involved shipboard tracking of adults in fjords off Norway and in the open ocean in the Japan Sea. Only recently has the size of ultrasonic tags become small enough so that they can be used to track salmon smolts within the river. Stand-alone receivers are now being used extensively within rivers and bays to detect juveniles carrying coded UF transmitters. "Curtain" arrays have been established across the Bay of Fundy on the northeastern coast of North America. Similar arrays have be established along the continental shelf mainly off the coast of Washington State and Canada, but an array exists as far south as off the Point Reyes Headlands in Central California, encompassing much of the geographical range of salmonids. There are multiple models of UF tags with different methods of coding – and this effects the range of tag detection and electronic life of the tag. These tags have been miniaturized even further so they can be placed on smolts < 110 mm TL, but the monitors detecting these tags are more expensive and their power supplies must be replenished more often than monitors capable of detecting slightly larger tags. A recent innovative approach to tracking has been to place both coded UF tags, detectable by monitors both in the river and ocean, and archival tags, which estimate position based on light and temperature measurements, on interoparous steelhead, which make repeated migrations in and out of the Sacramento River and coastal rivers of Central California.

Deliverable

(1) Klimley, A.P., P.T. Sandstrom1, R.B. MacFarlane, and S.T. Lindley. 2011. Insights into salmon migration from innovations in electronic tagging: past, present, and future. *Env. Biol. Fishes*, *Special Issue*.

Task 2: Expansion and Maintenance of Array of Tag-detecting Monitors in Sacramento River and San Francisco Estuary

We deployed automated tag detecting monitors in the mainstem of the Sacramento River (Fig. 1). These monitors were either deployed singly within the channelized river or in pairs, each separated by 100 m, in the upper reaches of the rivers consisting of runs, riffles, and pools. The spacing of the monitors was dependent upon the range, at which they detected a salmon smolt carrying a coded beacon. The results of range tests within river, delta, and bay were presented at the 4th biennial CALFED Science conference (Sandstrom *et al.*, 2006) and the 8th biennial State of the San Francisco Estuary Conference (Ammann *et al.*, 2007).

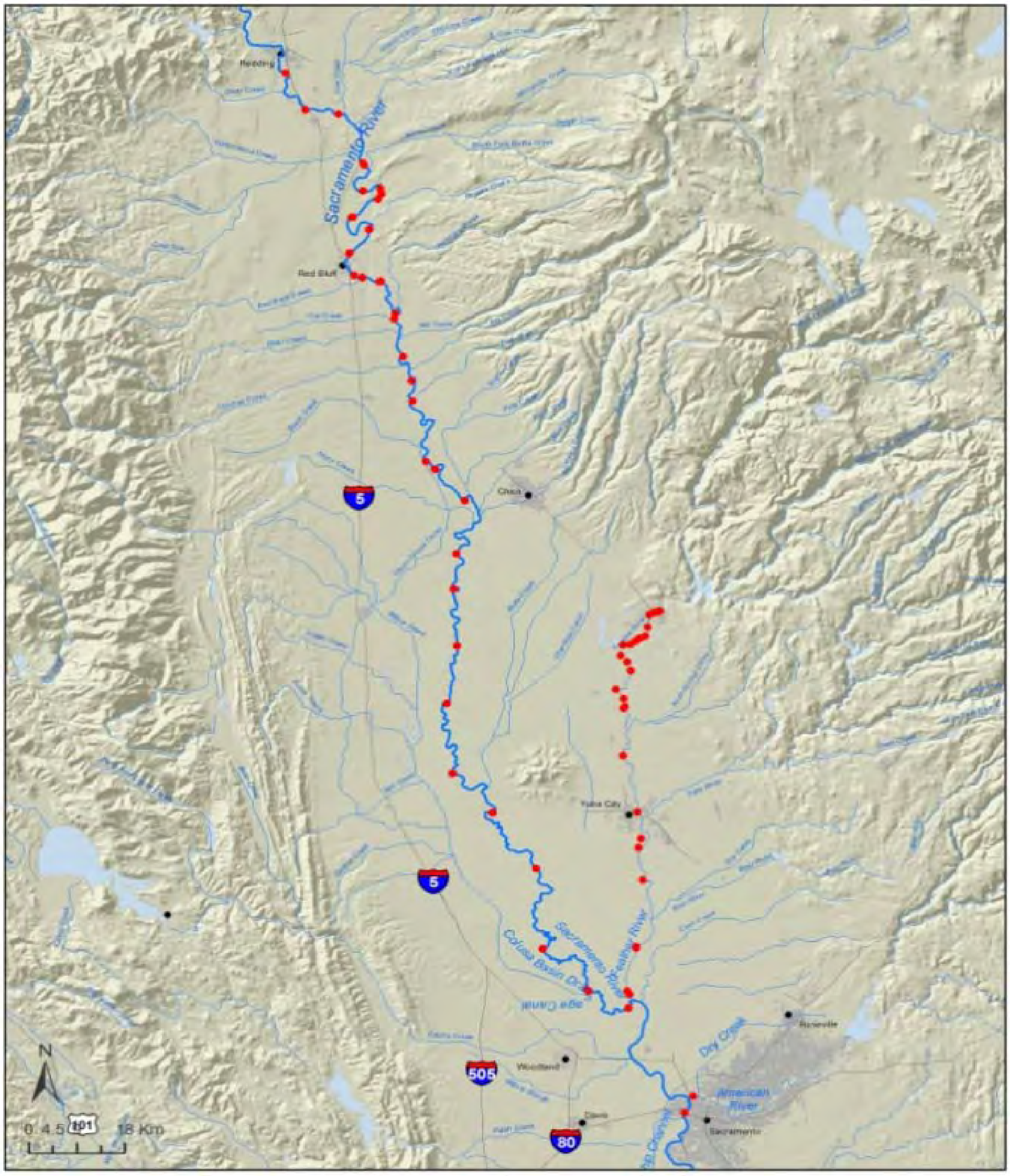


Fig. 1. Automated tag-detecting monitors deployed by UC Davis investigators in the mainstem of the Sacramento river. Red circles = monitor sites.

The array of monitors was expanded into the Delta with funding to the Biotelemetry Laboratory at UC Davis from the California Department of Fish and Game (Fig. 2). These monitors were used by Perry *et al.* (2006) and Perry *et al.* (2011) to show a greater survival of salmon smolts during their downstream migration when the Cross Delta Channel was closed during December than when it was opened during January 2006 and 2007. The array was also used to determine the proportion of juvenile and adult steelhead remain (residualize) within the Mokelumne River or continue migrating through the Delta, into San Francisco Bay, and out into the ocean (Workman *et al.*, 2008; Del Real *et al.*, 2011).

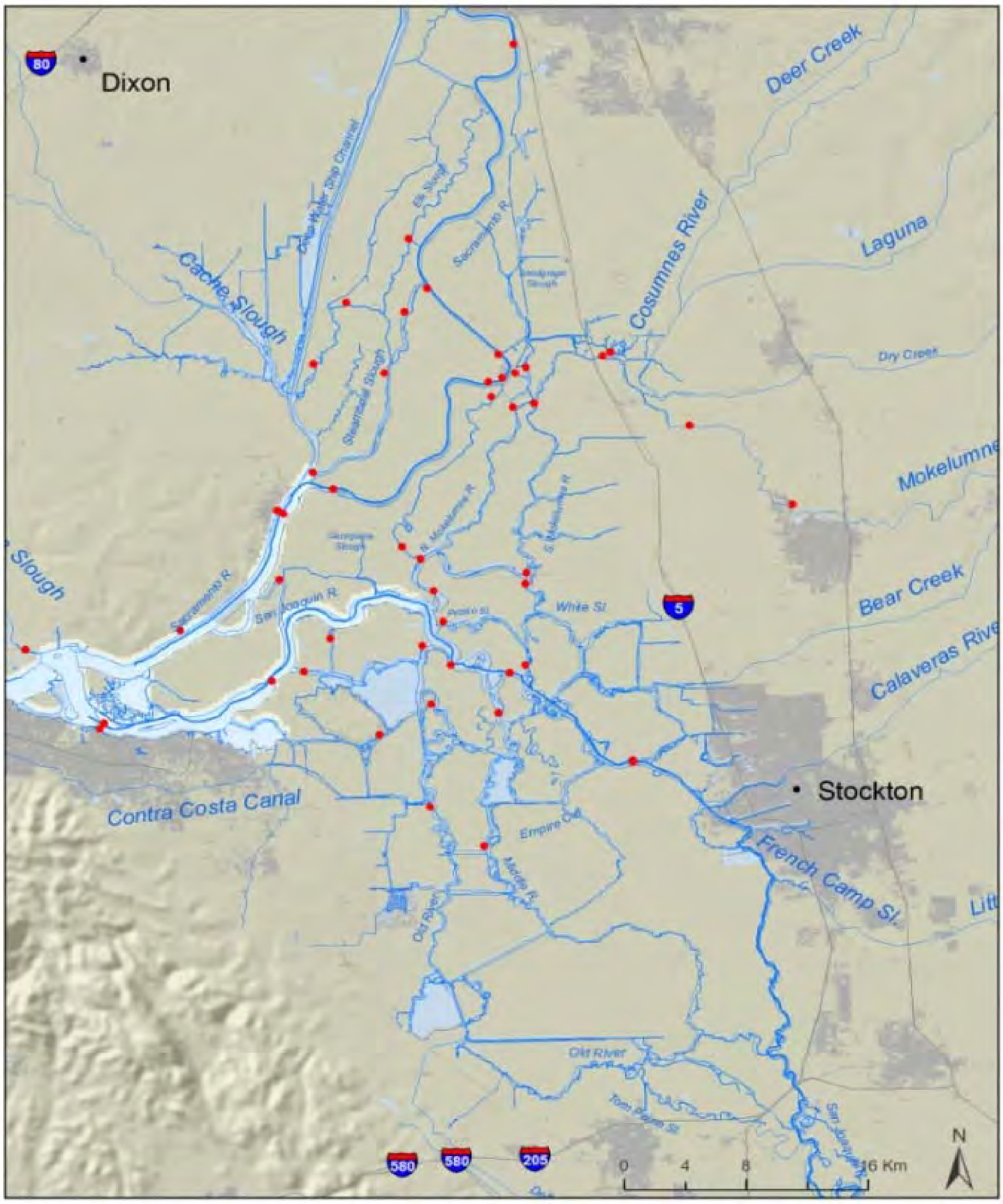


Fig. 2. Tag-detecting monitors deployed throughout the Delta, the Mokelumne River, and base of the San Joaquin River. Red circles = monitor sites

Monitors are maintained with matching support by the Biotelemetry Laboratory of UC Davis throughout San Francisco Bay with funding from the United States Army Corps (Fig. 3). These monitors are being used to determine whether salmon and steelhead smolts pass through the bay during dredge removal and deposition and might be affected by these activities. Singer *et al.* (2011) compared the rates of survival of salmonids during dry and wet years at these sites. This array consists of cross-bay, 'curtain' arrays at the Benicia, Carquinez, and Raccoon Straits, Richman-San Rafael and Bay Bridges, and before and after the dredge deposition site in San Pablo Bay.

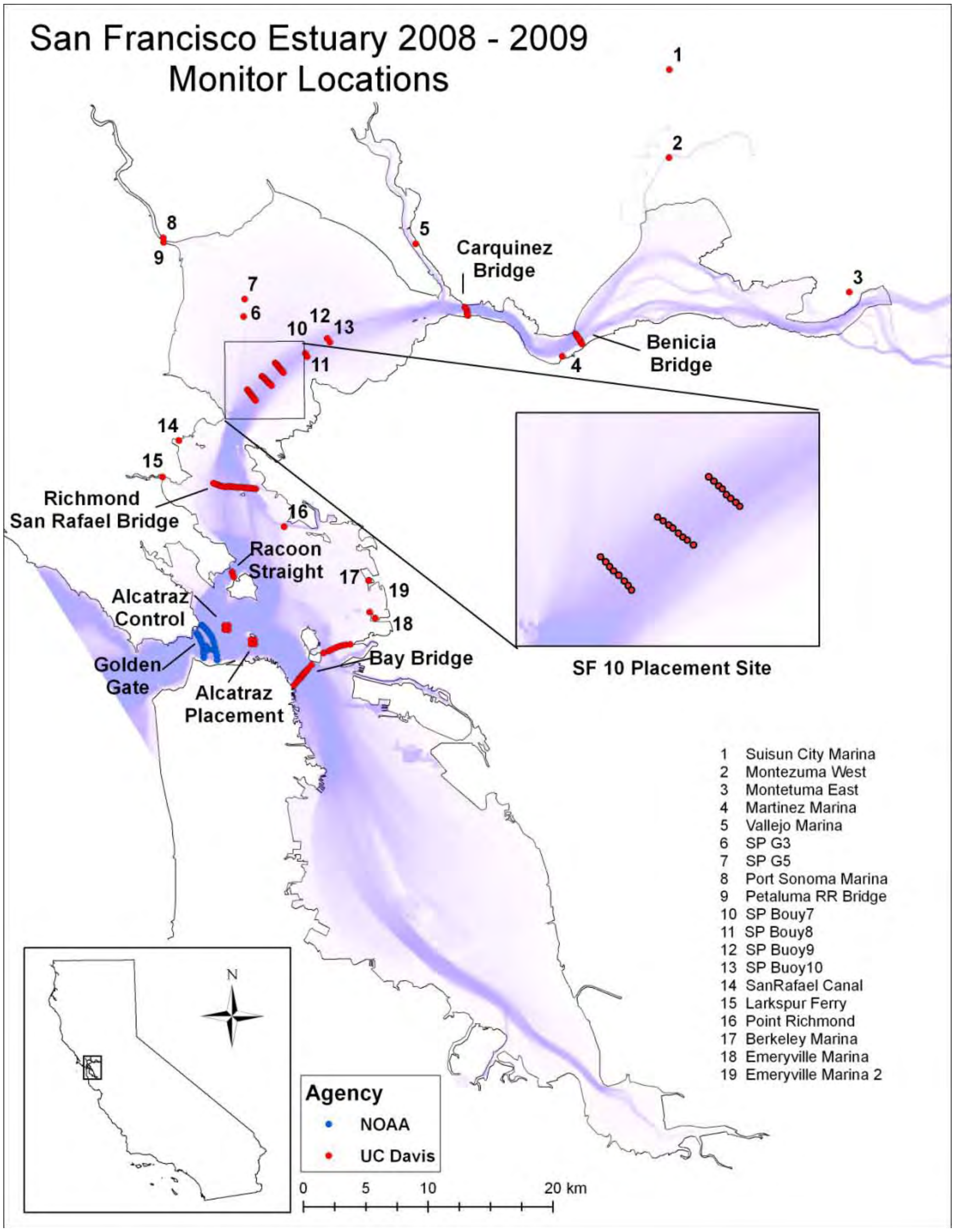


Fig. 3. Tag detecting monitors deployed in the San Francisco estuary. Red circles are monitors maintained by UC Davis; blue monitors serviced by NMFS..

Monitors are also in place at the mouths of the Napa and Petaluma River, the Oakland and San Francisco ports, and many marinas along the shores of the bay. The National Marine Fisheries Service maintains two lines of monitors at the mouth of the San Francisco Bay and one line of monitors crossing the continental shelf leading offshore from the Point Reyes Headlands. These monitors provide insight into the fate of the salmon smolts that leave the bay and enter the ocean. The effectiveness of the former array was determined by detections of long-term stationary tags and those on juvenile steelhead, Chinook salmon, seven-gill sharks, and green sturgeon during different tidal conditions (Ammann, 2010). The frequency of tag detection generally decreases with increasing current speed. However, the pattern is asymmetrical with respect to current direction (ebb or flood tide). Generally detection efficiency is higher during flood tide currents.

There are roughly 300 tag-detecting monitors in the Sacramento/San Joaquin watershed. The majority of these are serviced by staff of the UC Davis Biotelemetry. The files of tag detections are downloaded three times each year during November, February, and June. This process takes from three to four weeks. Investigators visit each monitor site in a vessel, remove the monitor from the water, and download the file on to a laptop's hard drive using either an optical or radio (Blue Tooth) interface. These files are reviewed before being sent via internet or surface mail to the staff of the Salmon Ecology Research Group at the Southwest Fisheries Center of NMFS in Santa Cruz, California. Here the files are entered into an ACCESS database, which includes the vital statistics of tagged species such as length, mass, sex, location , and date of tagging. This database is not reserved solely for juvenile salmon smolts, but for adult salmon and steelhead and many other species tagged within the watershed such as striped bass, white and green sturgeon, and cow sharks. These fish are tagged by investigators from numerous consultant firms, municipal, state, federal agencies, and universities:

1) consulting firms, Cramer Fish Science, ECORP Consulting, Inc., ENVIRON INTERNATIONAL, and H.T. Harvey & Associates,

2) municipal agencies, East Bay Municipal Utilities District, ports of Oakland and San Francisco,

3) state agencies, California Department of Fish and Game and California Department of Water Resources,

4) federal agencies, U.S. Army Corps., Sacramento and San Francisco, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Geological Service, and

5) universities, Stanford, UC Davis, UC Santa Cruz, and University of Washington.

Investigators from these institutions can search the ACCESS database for the times that tagged fish pass each monitor. They must learn how to use the database software either by reading a book (i.e., Dummies for ACCESS) or taking a class given at a junior college or university. UC Davis maintains a website for the 'California Fish Tracking Consortium', on which there is a page with a menu that permits investigators to input a tag identification number and provides a list of the times at which the fish were detected at monitors within the array. We are investigating the possibility of setting up a database, called 'Hydra', software created for the many arrays of monitors in the Pacific northwest.

We include in this task two studies, which utilized our monitor array to determine the movements from other species than salmon smolts. Null *et al.* (2011) placed coded acoustic transmitters on steelhead kelts that had returned to spawn at the Coleman Fish Hatchery to demonstrate that they make a second migration to sea after which they return to the hatchery again. The predominant migration pattern was characterized by short-term residence near the release site at Battle Creek following the release of kelts in early April, followed by rapid and sustained downstream movement once migration was initiated. The kelts arrived at the Golden Gate Bridge from April to mid-July. While most emigrated, at least nine percent remained in freshwater. Repeat spawning migrations began from late-September through October of the year of release, and the steelhead returned to Battle Creek from late-September through November. The adult steelhead showed high fidelity to Battle Creek with only one of fifteen surviving fish straying to a non-natal spawning area. Iteroparity was high with 36% and 48% of fish making a second spawning migration in 2005 and 2006, respectively.

Teo *et al.* (2011) placed archival and coded acoustic tags on 14 reconditioned steelhead that were released from Coleman National Fish Hatchery. Two of these steelhead kelts were recovered at the hatchery after 219 and 285 days at liberty respectively. One steelhead moved into coastal California waters while the second remained in freshwater for the majority of its time at liberty. Large increases in temperature and opacity were recorded before and after the ocean phases, likely as the steelhead moved through the Sacramento Delta. The two steelhead kelts remained relatively close to the surface throughout their migration, but there were diurnal differences in the vertical movements. In freshwater, the steelhead was deeper during the day but in the ocean the steelhead swam deeper during the night.

Abstracts from Scientific Talks and Posters

(1) Sandstrom, P.T., A. J. Ammann, L.L. Schlipp, A.P. Klimley, and R.B. MacFarlane. 2006. The Range of Detection of Ultrasonic Tags by Automated Monitors in the Sacramento San Joaquin Watershed. Poster, 4th Biennial CALFED Science Conference, Sacramento.

The range of detection of ultrasonic tags by automated monitors in the Sacramento San Joaquin Watershed

We have determined the distance of detection of two miniature ultrasonic beacons (V-07 & V-09, Vemco Ltd.), which will be implanted within salmonid smolts, allowing smolt movement to be detected by automated monitors (VR-02) that will be deployed in the Sacramento River and throughout San Francisco Bay in November of 2006. These monitors will be used to track the outmigration of salmon smolts from January to March over the next three years. Range tests performed in the bay consisted of deploying six monitors placed at depths of 1, 5, 10, 15, 20, and 25m from the surface, fastened to a single mooring, consisting of an anchor, polypropeylene line and surface float. Beacons of both models, V-07 and V-09, were lowered to depths of 1, 5, 10, 15, 20, and 25m and held at each depth until ten pulse bursts were detected by a portable receiver (VR-100) operated from a research vessel stationed above the tags. This experimental paradigm will allow us to select the optimal depths of which to deploy receivers under different environmental conditions. Tests have been conducted during weak and strong tidal flows. Strong flows can result in tilting of the monitors, and reduce the detection rate. The maximum range of detection, to date under Sea State 1 and moderate ebb flow conditions, for the V-07 at a depth of 10m and a monitor at similar depth was 234m. Using a range of information we will determine the optimal spacing of the automated monitors to fully detect tagged smolts as they migrate from the river and through the bay.

(2) Ammann, A.J., P. Sandstrom, E. Chapman, C. Michel, A. P. Klimley, S. Lindley, and R. B. MacFarlane. 2007. The performance of Vemco V7, V9 and V16 transmitters and VR2 receivers under varying environmental conditions. Poster, 8th Biennial State of the Estuary Conference, Oakland

The performance of Vemco V7, V9 and V16 transmitters and VR2 receivers under varying environmental conditions

The use of acoustic telemetry systems to monitor behavior, migration, and survival of aquatic animals is increasing rapidly. Acoustic systems offer many advantages over more traditional mark and recapture methods, although performance of acoustic equipment can vary dramatically depending on environmental conditions. Proper selection and design of an acoustic tagging and monitoring program requires understanding of how performance varies in different habitats and under varying wind, current, and water conditions. We present data characterizing the maximum detection range of Vemco transmitters of variable power output and the percent of transmissions received over increasing distances by Vemco VR2 receivers. Tests were conducted in lake, river, and bay habitats. These results can be applied to the configuration and placement of receivers.

Benchmark and field tests of the range of automated monitors for three sizes of ultrasonic transmitters

Gabriel Singer[1], Arnold Ammann[2], Phil T. Sandstrom[1], Cyril Michel[2], Eric D. Chapman, R. Bruce MacFarlane[2] and A. Peter Klimley[1]
[1] University of California Davis, Biotelemtry Laboratory
[2] NOAA Fisheries, Southwest Fisheries Science Center

Range testing of Vemco acoustic technology was conducted in various environmental settings. We range tested three sizes of acoustic transmitters. The factors contributing to noise in the study sites were described. Three different sites were selected that were representative of the monitor locations selected for our array. Tests were conducted to determine the effective range for three sizes of ultrasonic transmitters. Comanche Reservoir was selected to represent a calm location free of interference. the Sacramento River at Freeport was selected to represent a slow moving river environment, and the San Francisco Bay was selected to represent an estuary with a strong tidal influence. Results of the range testing concluded that areas with high levels of noise greatly affected the rate of detection efficiency of the monitors. Based on the results of the range testing a general model was created to help determine the effect range of a monitor in a site with a specific noise level. The model is applicable to study sites in which range testing has not been conducted, and proved to be an important tool that can be used to optimize the effectiveness of an array of monitors.

(4) Ammann, A.J. 2010. Monitor Detection Efficiency and Tidal Currents. Talk, Symposium: Electronic Tagging Studies of Salmon Migration, Bodega Marine Laboratory, Bodega Bay.

Monitor Detection Efficiency and Tidal Currents

I examined patterns in acoustic detections at the Golden Gate Bridge with relationship to currents. Both long term stationary tags and detections for juvenile steelhead, Chinook salmon, seven-gill sharks, and green sturgeon were binned into 15min intervals and compared with corresponding current speed and direction. The number of detections per 15min bin generally decreases with increasing current speed. However, the pattern is asymmetrical with respect to current direction (ebb or flood tide). Generally detection efficiency was higher during flood tide currents. Patterns of detection efficiency were different for each species. This analytical approach can be helpful in interpreting detection records of individuals or species.

Deliverables

(1) Null, R.E., K. S. Niemela, and S.F. Hamelberg. 2011. Post-spawn migrations of hatchery-origin *Oncorhynchus mykiss* kelts in the Central Valley of California. Special Issue, *Env. Bio. Fishes*.

(2) Teo, S.L.H., P.T. Sandstrom;, E.D. Chapman, R Null, K. Brown, A P. Klimley, and B.A. Block. 2011. Archival and acoustic tags reveal the post-spawning migrations, diving behavior, and thermalhabitat of hatchery-origin Sacramento River steelhead kelts (*Oncorhynchus mykiss*). Special Issue, Env. *Bio. Fishes*.

Task 3: Monitoring Outmigration of Late-Fall Run Juvenile Chinook Salmon and Steelhead Trout

We placed individually coded acoustic beacons on hatchery raised late-fall Chinook and steelhead smolts for this study. The number of smolts tagged and the release varied slightly between years. A total of 1400 juvenile salmon and 1400 juvenile trout from Coleman National Fish Hatchery were tagged and released over the course of the past five years. In the first year of study, fish were released in small groups each day directly into Battle Creek, the tributary on which the Coleman National Fish Hatchery is located. A large number of fish were not detected post release. Because of the high loss of individuals in Battle Creek during the first year of study, fish were released during the subsequent three years at two different times, December and January, at three different locations, Jelly's Ferry, Irvine Finch, and Butte City. In the fifth year of study, fish were released from Jelly's Ferry at two separate times, December and January. After determining that steelhead trout shed tags at a significant rate, we switched from the use of a 9 mm diameter tag to the smaller 7 mm diameter, cylindrical, acoustic coded tag.

Annual Release Schedules

Year 1. During 2006-2007, steelhead trout were released in groups of 12 or 13 individuals each day, Monday-Friday, in the mainstem Sacramento River at the Balls Ferry Bridge, Anderson, CA. The late-fall Chinook salmon were also released in the same numbers but from a different location, Battle Creek, the tributary that runs from Coleman National Fish Hatchery to the Sacramento River. The hatchery does not release steelhead directly into Battle Creek, rather they release them in the mainstem Sacramento River. That is why the steelhead were released at a different location than the late-fall Chinook salmon. The release methodology was used in order to space out fish and examine survival over the course of time. During the first year of study we noticed a high rate of loss in late-fall Chinook salmon and low overall success of both species during their downstream migration to the Golden Gate.

Year 2. Both the numbers and release strategies were changed because of the low survival success of individuals during the first year of study and difficulties associated with large errors in the survival estimates. We examined various release schedules to identify what release strategy had the highest potential to give us the highest confidence in our survival estimates (Lindley *et al.*, 2005). This best solution was to increase the sample size and release more fish at one time at multiple sites further downstream. The smolts were released during 2007-08 at night during December and January at three different locations along the mainstem of the Sacramento River: Jelly's Ferry, Irvine Finch, and Butte City.

Years 3 & 4. During the second year, fish were held to observe their behavior, survival, and healing following the surgical procedure. Several of the steelhead trout were noted to have lost their tag during the holding period. This was a concern because it had the potential to negatively bias the steelhead trout survival estimates. We subsequently conducted a tag retention experiment to determine to what degree this might affect the survival estimates and whether various factors such as tag size affect the outcome of tag retention (Sandstrom et al., 2011). From the study with steelhead trout from Coleman National Fish Hatchery, we were able to determine that fish carrying V7 and V9 tags shed the coded beacons at a rate of 15% and 25%, respectively. In light of this outcome, we placed V7 transmitters in the peritoneum of both species during the rest of the study. The same release methodology was used in 2008-09 and 2009-10.

Year 5. During years 2-5 we noticed steep declines in survival at two release sites for the late-fall Chinook salmon. A similar pattern was observed for steelhead trout at all three release sites during both releases, December and January. During the final year of study, fish were released at two different times of year from a single location a night anticipating that this would help to minimize the impact of initial mortality upon release in the mainstem of the Sacramento River.

Studies of Salmon Outmigration

Two studies were carried out on the effect of tagging on salmon smolts. Ammann *et al.* (2010) determined the rates of growth, survival, tag retention, and swimming performance in hatchery raised, yearling Chinook salmon juveniles carrying acoustic beacons within their peritoneum. Sandstrom *et al.* (2011) recorded the growth and tag expulsion rate of tagged juvenile steelhead trout. Two tag types of differing sizes were used to examine the impact of tag mass on peritoneal retention and survival rates. Implanted within the peritoneum of juvenile trout were 40 cylindrical tags with a 9 mm diameter (V9, Vemco Ltd.) and 40 tags with a 7 mm diameter (V7, Vemco Ltd.). Ten larger beacons were expelled between day 19 and day 65. Six of the smaller tags were expelled between day 21 and day 142. We incorporated a probabilistic and a simple individual removal approach to compensate for tag loss in determining survival estimates.

One study (Michel *et al.*, 2010) was devoted to determining reach specific rates of movement of juvenile Chinook in the mainsteam of the Sacramento River. River region had a significant effect on movement rates. Smolts migrated mostly at night while in the upper regions of the river but moved throughout the day in the lower river, delta, and estuary. Of numerous environmental variables analyzed for covariance with movement rates, river sinuosity, width-to-depth ratio, river channel velocity, flow, and temperature, all were found to have potentially important influences. These were all positive relationships with movement with the exception of width-to depth ratio. Yearly and regional fluctuations in movement rates are in agreement with predicted influence of river velocity having a positive relationship with movement rates. Zajanc *et al.* (2011) examined the effect of the levee modifications on the movements of juvenile Chinook salmon and steelhead trout in the mainstem of the Sacramento River. For Chinook, they found that the probability of holding increased as bank slope, wood cover, and fine substrates increased and holding time increased as wood cover increased. For steelhead, the holding time increased as large (i.e., cobble/boulder) substrate and wood diversity increased. They found support for three research and management implications: 1) release location influences the probability of holding and holding time for both species, and could potentially be managed to increase holding in areas with typically greater survival; 2) downstream migratory behaviors of Chinook salmon and steelhead smolts are different and conclusions regarding one species cannot necessarily be applied to the other, and 3) certain qualities of habitat features, such as high density and diversity of large woody material, should be incorporated into bank rehabilitation projects to increase cover from predators and provide velocity refuge, improving holding habitat and likely improving survival during downstream migration.

Two studies (Perry *et al.*, 2010, 2011) were devoted to determining the relative survival of salmon smolts released at the confluence of the Sacramento River with the delta as they passed through different routes on the way to the bay. In the former, the percentage of juvenile salmon reaching the bay was greater when the Delta Cross Canal (DCC), which permits more water to enter the interior of the delta, was closed later during the winter. Steel *et al.* (2011), using monitors configured to provide 2-D tracking, found that smolts, encountering the juncture when there were high water velocities in the Sacramento River or low water velocities in the DCC, were significantly more likely to remain in the Sacramento River.

Singer *et al.* (2011) compared the rates of survival of salmon smolts in the delta versus the bay. Less than 25% of fish released above Sacramento migrated successfully to the Pacific Ocean in both years. They found that reach specific success of >60% was greater in the Delta in 2009 than the <33% in 2010, whereas this pattern was reversed in the Bay (<57% in 2009, >75% in 2010).

Survival was also studied in other rivers in the Sacramento/San Joaquin watershed. The Napa River is a small stream that drains into the San Francisco Bay Estuary and hosts a run of Central California Coast steelhead. Steelhead appeared to exit the system at mostly age class 1+ and older, ranging in size from 123 mm to 270 mm (Sandstrom et al., 2010). Sixty-six percent of all fish tagged in this study successfully migrated from the Napa River and entered the San Francisco Bay Estuary, 71 percent of these individuals successfully reached the coastal ocean, and 60 percent of the fish that entered the ocean were detected on the Point Reyes line of monitors approximately 60 km north of the Golden Gate. Fish in the coastal ocean appeared to move at a rate that was dependent upon their size -- the larger fish moved more quickly. Del Real *et al.* (2011) conducted a three year acoustic tagging study to evaluate the migratory characteristics of hatchery and natural-origin steelhead during their downstream migration to the Pacific Ocean. Results from this study revealed that there are significant differences in the proportion of hatchery and natural steelhead that demonstrate downstream movement. Fish origin, size, and release location all had a significant effect on whether an individual exhibited downstream movement. Mokelumne-origin steelhead that initiated downstream movement, utilized numerous migration routes throughout the Delta during their migration towards the Pacific Ocean. They identified four primary migration pathways from the lower Mokelumne River through the Sacramento-San Joaquin Delta, while the Delta Cross Channel was closed.

Finally, Hayes *et al.* (2011) placed tag-detecting monitors of elephant seals that make extensive migrations throughout the northern Pacific Ocean. These were able to detect tagged great white sharks, salmon smolts (which we had tagged) and other elephant seals. They also proposed several alternative directions for future effort: 1) analyzing the growing number of passive acoustic survey recordings made from hydrophone arrays for acoustic tag detections, 2) working with acoustic technology providers to develop hull-mounted receiver systems that could be deployed on the thousands of ocean going vessels around the world and 3) integrating acoustic receiver technology into the thousands of moored and drifting oceanographic buoy arrays.

Abstracts from Scientific Talks and Posters

(1) Ammann, A.J., N. Kashef, D. Stafford, and R.B. MacFarlane. 2006. Effects of surgically implanted ultrasonic transmitters on the swimming performance and growth of hatchery steelhead smolts . Poster, 4th Biennial CALFED Science Conference, Sacramento.

Effects of surgically implanted ultrasonic transmitters on the swimming performance and growth of hatchery steelhead smolts .

When attaching or implanting any kind of physical tag to a fish it is essential to know how that tag affects the behavior, growth, and survival of that fish. Only when the tagging procedure and the tag itself do not negatively impact the fish can results of tagging experiments be expanded to the greater population. However, this can only be ascertained by a study that compares tagged fish to controls. We present the results of a laboratory study to examine the effect of surgically implanted ultrasonic dummy tags on the swimming performance and growth of hatchery-reared juvenile steelhead (*Oncorhynchus mykiss*). The dummy tags were the same size, weight, and material as functional tags, but without the electronics and battery. These results suggest implanting ultrasonic tags of these sizes into 147-210mm FL steelhead should not significantly impact swimming performance or growth. The tag expulsion rate was high, 2 out of 13 fish, although this was probably a result of the suture area inflammation caused by the silk sutures. Subsequent work has found that monofilament sutures do not illicit this response. These findings add support to the feasibility of using ultrasonic telemetry technology to address CALFED Program goals and objectives related to the impact of water management projects on migration and movement of juvenile salmonids.

(2) Sandstrom, P.T., A.J. Ammann, A.P. Klimley, R.B. MacFarlane, S.L. Lindley, E.D. Chapman, C. Michel, T. Pearson. 2007. Fine-scale movement and depth distribution of steelhead in the Sacramento River and San Francisco Bay. 4th Biennial CALFED Science Conference, Sacramento.

Fine-scale movement and depth distribution of steelhead in the Sacramento River and San Francisco Bay

Little is known about the movement patterns of juvenile steelhead. As part of a larger project using acoustic technology focusing on the migratory movements of juvenile steelhead and Chinook salmon in California's Central Valley, this project examines habitat preferences and fine scale spatial movements of individual fish, including swimming depth. These data will allow characterization of the behavior and movements of juvenile steelhead in relation to temperature, salinity, diel patterns, and flows. It will allow better understanding of locomotor behavior occurring between acoustic receiver sites in relation to habitat features and environmental conditions rather than assuming constant swimming speed and depth. Three hatchery juvenile steelhead tagged were tracked with Vemco® V9 ultrasonic pressure sensing tags. Through use of these tags it was possible to record fish position and depth for multiple days. In addition to collecting information on fish position and depth, physical parameters such as temperature, salinity, dissolved oxygen and turbidity were recorded using a Hydrolab® water quality sonde. Tracks were conducted during summer and winter to examine seasonal variations.

By characterizing movement patterns of these smolts we will be able to better understand what behaviors other tagged juvenile steelhead may be exhibiting between automated receiver sites along the outmigration corridor at various times of the year.

(3) Michel[1], C.J.*, A. Ammann[2], P. Sandstrom[3], E. Chapman[3], S. Lindley[2], A. Klimley[3], R. MacFarlane[2]
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A High-resolution Account of the Survival and Movement Rates of Acoustically Tagged Juvenile Chinook Salmon (Oncorhyncus tshawytscha) during the 2007 and 2008 Season

Acoustic tagging and tracking has become a very simple, high-resolution way of understanding fish movements. This method is essential in understanding the movements of highly migratory fish such as the late-fall run Chinook salmon (*Oncorhyncus tshawytscha*) smolts as the make their way through the Sacramento River watershed. We are specifically interested in learning more about their survival and timing of their downstream migration using an array of monitors throughout the watershed. This information, coupled with different morphological and environmental variables, will allow us to evaluate and understand their migration patterns. Initial results from 2007 data showed very low survival in the upper Sacramento river, with very few smolts making the 530 kilometer journey from release at the Coleman National Fish Hatchery to the Golden Gate Bridge. The few that did make it to the ocean took an average of 25 days to make the trek. Data from the 2008 season is being analyzed and will also be presented.

CALFED Statement of Relevance
By providing invaluable high-resolution movement and survival information for these economic and ecologically important fish, we will be able to assess the impacts of anthropogenic and natural factors on the population. This could lead to improved management and conservation efforts to help curtail their decline.

(4) Sandstrom, P.T., P. Klimley, B. MacFarlane, S. Lindley, A. Ammann, E.Chapman, C. Michel. 2008. California Fish Tracking Consortium: Survival and Migratory Patterns of Central Valley Juvenile Salmonids. 5th Biennial CALFED Science Conference, Sacramento.

California Fish Tracking Consortium: Survival and Migratory Patterns of Central Valley Juvenile

High resolution data is being collected on juvenile salmonids through the use of acoustic telemetry. The development of miniature acoustic tags has made it possible to tag fish Coalition/E-CORP. under 140 mm fork length, and automated monitors allow for continuous sampling at multiple sites. In 2007 the California Fish Tracking Consortium (CFTC) was formed. The consortium is comprised of research, academic, resource and consulting agencies. This group downloads and maintains a large array of acoustic monitors throughout the San Francisco Bay Estuary, Delta, Sacramento River, Cosumnes River, Mokelumne River, American River, San Joaquin River, Yuba River and Feather River. The group has tagged more than 700 juvenile salmonids and released fish in various locations according to researcher's specific questions. In the second year of study the CFTC tagged more than 1000 juvenile salmonids and deployed additional monitors to improve detection probabilities and resolution of specific river reaches. Several other groups have joined the consortium in the past year, increasing the number of automated monitors deployed throughout the watershed and the number of rivers containing monitors. This cluster poster presents the work of members of the CFTC concerned with the migratory movements, success rates, and behaviors of central valley juvenile salmonids. The cluster presents CALFED funded studies by the University of California Davis and NOAA's Southwest Fisheries Science Center, as well as research conducted by other CTFC members such as East Bay Municipal Utilities District, Department of Water Resources, U. S. Fish and Wildlife Service, U. S. Army Corps of Engineers, and the Bay Planning Coalition/ECORP.

(5) Sandstrom, P.T., A. J. Ammann, A.P. Klimley, R.B MacFarlane, S.L. Lindley, Eric D. Chapman, C. Michel. 2008. *Fine-scale movement and depth distribution of steelhead in the Sacramento River and San Francisco Bay.* 5th Biennial CALFED Science Conference, Sacramento.

Fine-scale movement and depth distribution of steelhead in the Sacramento River and San Francisco Bay.

Little is known about the movement patterns of juvenile steelhead. As part of a larger study using acoustic technology focusing on the migratory movements of juvenile steelhead and Chinook salmon in California's Central Valley, this project examines habitat preferences and fine scale spatial movements of individual fish, including swimming depth. Throughout the first year of the larger central valley fish tracking consortium study we have observed numerous juvenile steelhead going undetected between acoustic monitors from 2-60 days before being detected again downstream. Acoustic monitors in this area are 3-10 km apart and there are two monitors at each site. The manual track data will allow characterization of the behavior and movements of juvenile steelhead in relation to temperature, salinity, diel patterns, and flows. It will allow better understanding of locomotor behavior occurring between acoustic receiver sites in relation to habitat features and environmental conditions rather than assuming constant swimming speed and depth. Three juvenile hatchery steelhead were tagged and tracked with Vemco® V9 ultrasonic pressure sensing tags. Through use of these tags it was possible to record fish position and depth for multiple days. In addition to collecting information on fish position and depth, physical parameters such as temperature, salinity, dissolved oxygen and turbidity were recorded using a Hydrolab® water quality sonde. Tracks were conducted during summer and winter to examine seasonal variations. By characterizing movement patterns of these smolts we will be able to better understand what behaviors other tagged juvenile steelhead may be exhibiting between automated receiver sites along the outmigration corridor at various times of the year.

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Estimating Reach-specific Smolt Survival Rates and the Factors Influencing them from Acoustic Tagging Data

Our extensive array of acoustic receivers arranged along the Sacramento River between Battle Creek and the Golden Gate, combined with releases of acoustically-tagged chinook and steelhead smolts, allows estimation of reach-specific survival rates. The analysis is complicated by the fact that not all live animals passing a receiver are detected. The Cormack-Jolly-Seber model in Program MARK can be used to obtain maximum likelihood estimates of reach-specific survival rates along linear portions of the river, and some amount of branching can be handled with multi-strata models. The effects of individual covariates (e.g., fork length) can be included to explain variation in survival or detection probabilities among individuals, and the effects of reach-related factors (e.g., bank cover, water velocity) can be included to explain variation in these parameters among reaches, potentially giving insight into the causes of variation in survival. We will present the results of such analyses for smolt release experiments conducted in 2007 and 2008.

CALFED Statement of Relevance
This project is providing for the first time high spatial resolution data on survival and movement of juvenile salmonids, which can be used to assess influences of natural and anthropogenic factors, such as flow, water temperature, diversions, and riparian habitat alteration, on salmonid populations.

SESSION: Migratory Movements and Success of Salmonids (I), 10/22/2008, 2:00 PM, Room 306

MacFarlane[1], B.R., A.P. Klimley[2], S.L. Lindley[1], A.J. Ammann[1], P.T. Sandstrom[1], C.J. Michel[2], E.D. Chapman[2]
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Survival and Migratory Patterns of Central Valley Juvenile Salmonids: Progress Report

We are in the second year of a three-year project describing reach-specific rates of survival and movement of juvenile late-fall Chinook salmon and steelhead. Variation in rates will be related to natural and anthropogenic covariates, such as water flow, water temperature, and riparian habitat use. This CALFED funded project rapidly grew to include other agencies (U.S. Army Corps of Engineers, U.S. Fish & Wildlife Service, East Bay Municipal Utility District, Bay Planning Coalition, and California Department of Water Resources) to address their salmon-related issues. In 2006, the consortium placed 220 acoustic receivers throughout the Sacramento River, Delta, and San Francisco Estuary that will detect the presence of tagged fish. In 2007, 200 late-fall Chinook smolts and 200 juvenile steelhead from Coleman National Fish Hatchery were tagged and released into the system near the hatchery. An additional 194 late-fall Chinook and 49 steelhead were tagged and released near Sacramento for Delta and Estuary related projects. High mortality (> 80%) was recorded between release near the hatchery and Ord Bend, 150 km downstream, for both species. Survival was about 10% at the west end of the Delta. Only 2% of the Chinook and 7% of the steelhead were detected at the Golden Gate. This very low survival may have been related to water conditions; 2007 was a dry year with low river flows, which may have resulted in high predation. Data analysis resulted in changes in release strategies and the number of tagged fish in 2008 to improve survival estimate confidence intervals downstream of the upper river high mortality section. In 2008, 304 Chinook and 300 steelhead were released in the Sacramento at three spatially separated locations, and an additional 471 Chinook and 50 steelhead were released downstream for Delta and Estuary studies. Data from the 2008 releases are currently be checked and added to the database.

CALFED Statement of Relevance
This project is providing for the first time high spatial resolution data on survival and movement of juvenile salmonids, which can be used to assess influences of natural and anthropogenic factors, such as flow, water temperature, diversions, and riparian habitat alteration, on salmonid populations.

SESSION: Migratory Movements and Success of Salmonids (I), 10/22/2008, 1:20 PM, Room 306

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Tag Effects in Yearling Salmonids with Implanted Acoustic Transmitters

The use of surgically implanted acoustic transmitters, coupled with an extensive array of receivers, is allowing researchers to track the movement and survival of juvenile salmonids. When implanting a tag it is essential to know that the tag and the tagging procedure do not negatively affect the fish. Additionally, tag expulsion rates should be determined for each tag type, fish species and size class. We performed laboratory trials to test how implanted tags affect the growth and survival of hatchery-raised yearling late-fall Chinook salmon and yearling steelhead. The Chinook were implanted with dummy tags similar to Vemco V7-4Ls, about 3.7% tag to body weight. Steelhead were implanted with tags similar to Vemco V9-1Ls, about 2.8% tag to body weight. Growth and survival rates of tagged fish were compared to untagged controls and surgery controls (25 fish per treatment). For each species, all treatments were held in the same tank, fed daily rations of 2% biomass, and examined, weighed and measured every 30-45 days. Chinook growth rates were similar among treatments. Steelhead growth rates were lower for the tag treatment. Survival was similar among treatments for both species. Tag expulsion did not occur in Chinook after 90 days, while 5 out of 25 steelhead expelled their tags within 30 days. These results suggest that late-fall Chinook yearlings are not greatly affected by tag implantation. In contrast, steelhead growth rates are affected and tag loss is significant. The results of this laboratory study will help interpret results of movement and survival data obtained from tagged fish released into Central Valley and San Francisco Bay systems.

CALFED Statement of Relevance

This study is providing data to support and interpret results of a large-scale salmonid tracking study funded by CALFED.

SESSION: Migratory Movements and Success of Salmonids (I), 10/22/2008, 1:40 PM, Room 306

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Migration Routes and Survival of Juvenile Late-fall Chinook Salmon Migrating through the Sacramento – San Joaquin River Delta

Understanding effects of water management actions on survival of juvenile salmon is critical to management of water and fisheries resources, but the complexity of the Sacramento – San Joaquin River Delta poses challenges in studying such problems. During 2007 and 2008, we acoustically tagged late-fall juvenile Chinook salmon and monitored their migration through the Delta. To better understand how survival among different migration routes contributes to overall survival through the Delta, we developed a mark-recapture model that explicitly estimates both the fraction of tagged fish using specific migration routes and survival within each route. In 2007, an estimated 30%-40% of juvenile salmon migrated through Steamboat and Sutter Slough, a migration route which precludes fish from being entrained into the interior Delta via the Delta Cross Channel or Georgiana Slough. Of fish that remained in the Sacramento River, an estimated 33% of fish entered the Delta Cross Channel when it was open, and approximately 15% entered Georgiana Slough regardless of whether the Delta Cross Channel was open or closed. Accounting for fish distribution among all routes, tagged fish had a 35% probability of being entrained into the interior Delta when the Delta Cross Channel was open and a 9% probability when it was closed. Although standard errors were large, estimated survival for fish migrating through the interior Delta was lower than survival in the Sacramento River, a finding consistent with previous research. However, survival through the interior Delta contributed less than other routes to overall survival through the Delta due to the lower fraction of fish migrating through the interior Delta. Although small sample size limits broad inferences from the 2007 data, this study, ongoing analysis of the 2008 data, and research in 2009 is beginning to shed light on processes affecting survival and movement of juvenile salmon through the Delta.

CALFED Statement of Relevance

Management actions taken under the Water Supply Reliability objective affect distribution of water through the Delta. The Ecosystem Restoration Program is aimed at supporting sustainable animal populations. Our study addresses both objectives by examining how water distribution in the Delta affects routing and survival of migrating juvenile salmon.

SESSION: Migratory Movements and Success of Salmonids (II), 10/22/2008, 3:20 PM, Room 306

Chapman[1], E.D., P.T. Sandstrom[1], A.J. Ammann[2], C. Michel[2], A.P. Klimley[1], R.B. MacFarlane[2], S.L. Lindley[2]
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Diel Migrations of Salmon Smolts in the Sacramento River, Delta, and San Francisco Bay Estuary

We have been able to track fine scale movements of chinook salmon, *Onchorhynchus tshawytscha*, and steelhead trout, *Oncorhychus mykiss*, in the Central Valley of California through the use of ultrasonic telemetry. Miniature, ultrasonic coded beacons were implanted within the peritoneum of 500 fish during January of 2007 and released at four locations throughout the Sacramento River and Delta. These fish have been detected by an array of monitors established throughout the watershed extending from Redding to the Golden Gate Bridge in the San Francisco Bay. The detections of chinook over the following months (January, February, and March) exhibited a diel pattern of migration, that is there are few detections during daytime and many during nighttime. This is likely because individuals remain within a confined area during the day moving little, and then become active at night swimming extensively downstream. Furthermore, the difference between the ratio of more frequent nighttime detections to less frequent daytime detections of chinook smolts decreases in the Delta and San Francisco Bay Estuary. Steelhead, which reside upriver longer, do not exhibit the same diel pattern to detections at any point during their out migration. There may be other environmental cues that stimulate migrations of steelhead such as rainfall events (see Sandstrom et al. poster), but it does not appear to be related to day length.

CALFED Statement of Relevance
Late Fall Chinook smolts are exhibiting diel patterns of migration which may help managers determine the use of water in the Sacramento River. These fish are traveling at night in the upper river and by limiting the use of pumps during the day we may be able to reduce mortality.

SESSION: Migratory Movements and Success of Salmonids (II), 10/22/2008, 3:40 PM, Room 306

(11) MacFarlane, R.B., A.P. Klimley, A.J. Ammann, P.T. Sandstrom, S. Lindley, and E.D.Chapman. 2008. Survival and migratory patterns of Central Valley juvenile salmonids: overview. Advances in Fish Tagging and Marking Technology Symposium, Aukland, New Zealand.

Until recent advances in acoustic tagging technology, assessing high spatial resolution movement patterns and survival of smaller fishes, such as juvenile salmonids, was not feasible. Now, we have established an array of 200 acoustic receivers to determine reach-specific movement and survival of juvenile Chinook salmon and steelhead during their emigration from the upper Sacramento River through the San Francisco Estuary to the ocean. These data will be analyzed with hydrologic, riparian, and other land use data to determine associations that can be used to model, and perhaps predict, juvenile salmonids dynamics in relation to environmental conditions. The results of the first year of a three-year study revealed similarities and differences in survival and movement between the two species. Both species had the greatest mortality, about 80%, in the first 145 km of the 520 km outmigration corridor. Only 7% of steelhead and 2% of late-fall Chinook smolts were detected by the acoustic receivers at ocean entry in this very dry hydrologic year. Mean swimming speeds differed between steelhead and Chinook salmon juveniles. Chinook salmon swam at 50 kmd^{-1}, whereas steelhead migrated at 14 kmd^{-1} with a few fish exhibiting evidence of residualization. The first year confirmed proof-of-concept in the utility of this a dense array of receivers to permit determination of areas of high mortality and areas of slower movement, suggesting nursery functions, for salmonids in the Central Valley of California, where all four Evolutionarily Significant Units are either listed by, or are candidates for listing, under the U.S. Endangered Species Act.

(12) Sandstrom, P.T., A.J. Ammann, A.P. Klimley, B.R. MacFarlane, S.L. Lindley, E.D. Chapman, and C. Michel. 2008. Fine-scale movement and depth distribution of steelhead in the Sacramento River and San Francisco Bay. Advances in Fish Tagging and Marking Technology Symposium, Aukland, New Zealand.

Fine-scale movement and depth distribution of steelhead in the Sacramento River and San Francisco Bay

Little is known about the movement patterns of juvenile steelhead trout. Three juvenile steelhead trout were tagged and tracked with miniature ultrasonic transmitters that recorded depth. Tagged steelhead made small initial movements for the first 24 hours after release. The two individuals tracked for multiple days exhibited a heavy response to tidal flows. Fish moving the greatest distances upstream or downstream were observed in the top three meters of the water column and closely followed changes in water flow direction. Steelhead trout were observed near the bottom of the water column, where influence of flow is reduced, when making fine-scale movements or ignoring the prevailing water flow. The fish tracked continuously for five days during the summer showed a diel pattern, moving during the daytime and typically holding in an area of less than 1km at night. This fish was found at depths $\leq$3m 86% of the total daytime detections. The second steelhead tracked during the spring, when juveniles are outmigrating, moved further at night than during the day for the first four days. This fish also exhibited behaviors of holding and localized movements during the daytime rather than at night. 81% of daytime detections were $\geq$3m in depth, while 79% of nighttime detections occurred in the top 3m of the water column. By characterizing movement patterns of smolts we will increase our understanding of the behaviors other juvenile steelhead may be exhibiting between automated receiver sites along the outmigration corridor at various times of the year.

(13) Sandstrom, P, Arnold Ammann, E. Chapman, C. Michel, R.B. MacFarlane, P. Klimley, and S. Lindley. 2009. Acoustic tag retention of steelhead trout (*Oncorhynchus mykiss*). Talk, Meeting of the California-Nevada Chapter, American Fisheries Society.

Acoustic tag retention of steelhead trout (Oncorhynchus mykiss).

Numerous acoustic tagging studies have been conducted to estimate survival and route selection of juvenile salmonids throughout the Pacific Northwest. When conducting such studies it is important to be able to accurately represent tag retention of the acoustically tagged species. Prior pilot studies had revealed significant tag shedding in juvenile steelhead trout, but not chinook salmon. Juvenile steelhead trout were taken from Coleman National Fish Hatchery and implanted with Vemco V7 and V9 tags and monitored over a period of 140 days, which is longer or equal to the life of V7 and V9 tags currently being utilized in the Sacramento River acoustic study. Fish were anesthetized while data on the condition, weight, length, incision, and tag bulge was recorded. Pictures of the fish and incision were taken each time the steelhead trout were examined. All incisions healed quickly, and by the end of the experiment only a single fish retained sutures. Steelhead trout shed 12.5% of V7 tags and 22.5% of V9 over the course of the experiment. Based on this data we have chosen to implant our fish with the smaller Vemco V7 tags rather than V9, even though the V9 tags are below the 5% tag to body weight rule often followed.

(14) Sandstrom, P.T., G. Singer, A J. Ammann, C.J. Michel, S.Lindley, R.B. MacFarlane, and A.P. Klimley. 2010. Sacramento River steelhead trout: comparing wild and hatchery smolts. Talk, Symposium, Electronic Tagging Studies of Salmon Migration, Bodega Marine Laboratory, Bodega Bay and 6th CALFED Science Symposium, Sacramento.

Sacramento River steelhead trout: comparing wild and hatchery smolts.

There has been little research on the migratory movements of wild steelhead trout in the Sacramento River. It has been hypothesized that wild smolts will have a higher survival rate and behave differently than hatchery smolts. In order to examine this question steelhead trout surgically implanted with Vemco V7 acoustic tags. 150 Coleman National Fish Hatchery smolts were tagged, and released, with 50 fish released at three locations (Jelly's Ferry RKM 517, Irvine Finch RKM 414, and Butte City RKM 363) during two different times of year, December 2008 and January 2009 for a total of 300 tagged individuals. 60 fish were captured in a rotary screw trap and implanted tagged from Mill Creek (RKM 462), a tributary to the mainstem Sacramento River. The purpose of this study was to track the migratory movements and survival of both wild and hatchery smolts throughout the Sacramento River Watershed. Route selection within the Delta and the success rate of fish navigating a particular route is also examined. The majority of steelhead, hatchery December (n=30), hatchery January (n=43), and wild (n=21) respectively, utilize the mainstem Sacramento River (63%, 48%, 47%) when moving through the Delta with considerable number of individuals using Georgiana Slough (20%, 25%, 28%), and a smaller proportion of fish using Steamboat (7%, 12%, 5%), Sutter (10%, 5%, 19%), and Miner Sloughs (0%, 9%, 0%). Fish that reached the Golden Gate Bridge migratory time averaged 20 (13-36 days), 23 (10-57 days), and 12 (10-15 days) days for hatchery December, hatchery January, and wild smolts.

Growth and swimming performance of Chinook salmon and Steelhead yearlings implanted with acoustic transmitters

Arnold J. Ammann[1], Cyril Michel[1], Philip Sandstrom[2], Eric Chapman[2], and Nicholas Delaney
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Surgically implanting an acoustic tag into a fish may impart a burden that can affect survival, growth, behavior, and swimming performance. Only when the tagging procedure and the tag itself do not impart an unacceptable burden, can tagging experiments be expanded to the greater population. However, this can only be ascertained by studies that compare tagged fish to controls. We present the results of several laboratory studies that examine the effect of surgically implanted acoustic tags on the swimming performance and growth of hatchery-reared yearling Chinook (*Oncorhynchus tshawytscha*) and yearling steelhead (*O. mykiss*).

Movement and mortality patterns of Central Valley juvenile late-fal run Chinook salmon (*Oncorhynchus tshawytscha*) and the environmental factors that shape them

Cyril J. Michel[1], Arnold J. Ammann[1], Philip T. Sandstrom[2], Eric D. Chapman[2], Steven T. Lindley[1], A. Peter Klimley[2] and R. Bruce MacFarlane[1]
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[2] University of California Davis, Biotelemetry Laboratory

Juvenile (smolt) emigration from riverine origins to the ocean is a period of high mortality for populations of Chinook salmon (*Oncorhynchus tshawytscha*) in California's Central Valley. Natural and anthropogenic factors within this system are thought to affect smolts movement and mortality rates. Recent advances in the miniaturization of acoustic telemetry have allowed tagging and tracking of late-fall run Chinook salmon smolts throughout the Sacramento River watershed to the Pacific Ocean. We tagged and released 200 to 300 smolts every year for three years from winter 2006/2007 to winter 2008/2009. An array of 330 acoustic monitors placed throughout the watershed provided high spatial resolution movement and mortality estimates. The average movement rate for late-fall run Chinook salmon smolts emigrating through the Sacramento River watershed was 30.4 ± 19.6 km·d^{-1}. Mortality was about 65 % in the upper 150 km of the Sacramento River, 32 % within the lower 200 km of the river, 40 % in the Sacramento-San Joaquin Delta (100 km), and 69 % in San Francisco Estuary (70 km: Chipps Island to the Golden Gate). There were significant differences among years ($P<0.05$) in both mortality and movement patterns. Water temperature, turbidity, speed; river depth, width, flow; number of water diversions, extent of rip-rap or levees, and riparian habitat type were evaluated as potential influences on movement rate and mortality. Consistent with the spatial course of mortality, values of variables associated with up-river habitats (e.g., clear water, shallower depth) related to greater mortality, confounding the ability to elucidate actual causative agents. Of all variables tested, only the proportion of time spent in each segment of the riverine emigration at night was positively correlated with movement rates. Knowing which variables influence movement and mortality, and to what extent, help understanding how migration dynamics are ecologically shaped, and will aid in the management of the species.

Using acoustic tags to understand the potential impact of exports on survival through the Delta.

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The impact of the State Water Project (SWP) and Central Valley Project (CVP) exports on juvenile salmon survival through the north Delta has been difficult to quantify. Coded wire tag (CWT) studies conducted by the USFWS have shown that juvenile Chinook salmon survival is lower in the interior Delta, compared to the mainstem Sacramento River, and potentially a function of water exports. Newman and Brandes (2010), determined there was a significant amount of noise associated with the relationship between exports and relative interior Delta survival – in part due to the lack of precision in survival estimates based on the recovery of coded wire tags. In addition, the past CWT experiments have not been able to estimate how many juvenile salmon from the Sacramento River enter the interior Delta and consequently how project exports may impact survival through the entire Delta. Three years of data have been obtained using VEMCO acoustic tags to determine 1) the proportion of tagged fish migrating from Sacramento that are diverted into the interior Delta with the Delta Cross Channel gates open and closed, 2) the relative difference in survival for smolts entering the interior Delta relative to those migrating down the mainstem Sacramento River and 3) whether the relative differences in survival for fish entering the interior Delta, estimated using acoustic tags, is potentially related to exports, similar to the that obtained using CWT's. The information obtained from this study will help us better understand the impacts of project exports on juvenile salmon migrating through the Delta.

Diel migrations of salmon smolts in the Sacramento River, Delta, and San Francisco Bay Estuary

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We have been able to track fine scale movements of Chinook salmon, Onchorhynchus *tshawytscha*, and steelhead trout, *Oncorhychus mykiss*, in the Central Valley of California through the use of ultrasonic telemetry. Miniature, ultrasonic coded beacons were implanted within the peritoneum of smolts and released at four locations throughout the Sacramento River and Delta. These fish have been detected by an array of monitors established throughout the watershed extending from Redding to the Golden Gate Bridge in the San Francisco Bay. The detections of Chinook over the following months (January, February, and March of 2007 and 2008) exhibited a diel pattern of migration, that is there are few detections during daytime and many during nighttime. This is likely because individuals remain within a confined area during the day moving little, and then become active at night swimming extensively downstream. Furthermore, the difference between the ratio of more frequent nighttime detections to less frequent daytime detections of Chinook smolts decreases in the Delta and San Francisco Bay Estuary. Steelhead, which reside upriver longer, do not exhibit the same diel pattern to detections at any point during their out migration. There may be other environmental cues that stimulate migrations of steelhead such as rainfall events and water releases from dams, but it does not appear to be related to day length.

Mobile Receivers: Releasing the mooring to see where fish go

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A great deal has been learned from the large scale deployment of acoustic tags on marine species and networks of riverine and marine receiver stations. While quite effective in the linear environment of river systems, marine receivers are limited in their ability to provide spatial information on fish movements and distributions due to a combination of costs, logistics, lack of off-shore technology and all complicated by the vast three-dimensional spatial scale organisms can move across in the open ocean. While there are visionary plans to establish large scale bottom mounted arrays incorporating suites of receiver technologies for everything from acoustic tags to tectonics and temperature. Coupled with associated fleets of AUVs, these arrays would increase the capacity to detect acoustically tagged organisms; however, this is far into the future. At the same time, each year millions of dollars of tags are being released into the aquatic environment with extended battery/transmission life and no potential for detection beyond coastal arrays. We have been exploring two new methods of tracking acoustically tagged species in the marine environment. The first is analyzing data from a towed hydrophone (sampled at 400kHz) used for extensive marine mammal acoustic surveys throughout the northern California Current. If tags are detected, we plan to work with acoustic technology providers to develop hull mounted receiver systems that could be deployed on everything from research vessels and fishing boats to cargo ships and oil tankers. In addition, we are taking advantage of alternative technologies that have been used to study movements of large pelagic fish and marine mammals- namely satellite and archival tag technology. We are using a new acoustic receiver, Vemco's Business Card Tag (BCT), which has been miniaturized to be carried by larger marine organisms. At this time, we have 13 BCT units deployed on adult Northern Elephant seals in combination with satellite tracking tags and time-depth temperature recorders. The elephant seal migrations are carrying BCT's on paths that run from the coastal California Current, through the Gulf of Alaska, and potentially west to the 180 degree line. The first round of receivers is expected to be recovered in late April and preliminary results will be presented at the meeting.

Pathways, timing and rates of migration for hatchery and natural origin steelhead, *Oncorhynchus mykiss*, from the lower Mokelumne River, Ca

Casey Del Real[1], Joseph E. Merz[2] and Michelle L. Workman[3]
[1] Fisheries Biologist, East Bay Municipal Utility District
[2] Cramer Fish Sciences
[3] U.S. FWS Stockton, CA

The lower Mokelumne River (LMR), in the Central Valley of California, supports a population of natural *Oncorhynchus mykiss*, and the Mokelumne River Fish Hatchery contributes hatchery produced smolts to the system annually. We compared migratory patterns of LMR *O. mykiss* of natural and hatchery origin over a three year period. Specifically we looked at timing, rates, and pathway utilization under variable release locations in tidal and non-tidal habitats in the Mokelumne River and Sacramento San Joaquin Estuary. Data reported is recovered from receiver locations deployed in the non-tidal reaches of the LMR, as well as receivers deployed throughout the Estuary by participants of the Central Valley Fish Tracking Consortium. Our study provides valuable information on differences in hatchery and wild *O. mykiss* migration characteristics and provides unique insight into migratory behavior of little studied non-Sacramento River origin salmonids.

Fine scale movement, habitat associations and survival of wild *Oncorhynchus mykiss* of the Mokelumne River, CA, from acoustic telemetry in standardized transects

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[3]USFWS, Stockton, CA

Acoustic telemetry can showcase individual habitat use among natural and altered landscapes to both elucidate ecological patterns and highlight potential management actions. The fine scale movement patterns and habitat associations of one hundred twenty-seven wild steelhead trout *(Oncorhynchus mykiss)* were monitored using acoustic telemetry in the Lower Mokelumne River, CA in 2007 and 2008. Fish were captured by boat electrofishing and rotary screw trap. After recovering from surgical implantation of Vemco V9 pingers, all fish were released at their capture site. Large-scale movement patterns were recorded using stationary tag readers placed throughout the Lower Mokelumne River, the Bay-Delta area and Golden Gate Bridge as part of the California Fish Tracking Consortium. We also boated 39km from Camanche Dam, the upstream limit to anadromy to tidal influence every two weeks in standardized transect surveys using a handheld hydrophone. This technique produced fine scale movement and habitat association data from between stationary readers. Goals of the study were to address questions of how individual wild *O. mykiss* move within and across ecosystems, what individual and habitat traits influence these movement patterns and what were the consequences associated with these patterns? Most individuals only moved short distances or not at all. These data show that rates of anadromy in the Mokelumne may be extremely low. There was also a strong positive relationship between number of moves per life and mortality in 2007, presumably due to increased risk of predation. Movement across the population peaked during March and August highlighting the importance of sufficient flows to benefit habitat and allow for migration during seasonal peaks. This study demonstrates the complex interplay between the environment and the life-history, movement, and ultimately, survival of individual *O. mykiss*.

Post-spawn migration of steelhead kelts in the Sacramento River Basin of California

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We monitored the migratory behavior of steelhead kelts using ultrasonic telemetry. Ultrasonic transmitters were surgically implanted into twenty-five hatchery-origin steelhead kelts at the Coleman National Fish Hatchery (NFH), located on Battle Creek, following the 2004/2005 and the 2005/2006 spawning seasons. Tagged fish were subsequently released from the hatchery in April of each year. Movements were monitored using a series of fixed-site receivers located throughout the Sacramento River and at the terminus of the Sacramento River estuary at the Golden Gate Bridge. Results from the first year of this study showed that migratory behavior (i.e., travel distance, route and rate) was highly variable among individual fish; however, some patterns of movement were observed. Egress from Battle Creek ranged from 1 to 38 days (median 18 d) for fish exhibiting downstream movement. Three fish appeared to reside in Battle Creek or the upper Sacramento River through the fall of 2005. Downstream migration was generally rapid once initiated. Most fish entered the Sacramento River estuary, and subsequently the Pacific Ocean, by the end of May (average emigration rate approximately 8.8 km/d). Fifteen steelhead emigrated using the main channel of the Sacramento River , whereas three steelhead emigrated using alternate routes through the estuary. Freshwater reentry occurred from late-September through October. Nine of the 25 tagged fish (36%) were detected in the upper Sacramento River basin from October through December 2005; seven reentered the Coleman NFH, one fish was harvested by an angler, and the fate of one fish was undetermined. Results will be summarized for both study years and management implications discussed.

Survival of juvenile late-fall Chinook salmon using different migration routes to negotiate the Sacramento-San Joaquin River Delta

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We developed a multistate mark-recapture model to estimate 1) survival of juvenile salmon using different migration routes to negotiate the Sacramento-San Joaquin River Delta, and 2) the probability of fish using each route. Since these parameters determine population-level survival, simultaneous estimation of both allowed us to quantify the relative contribution of each migration route to population-level survival. We applied this model to three years of acoustic telemetry data (2007-2009) with releases made when the Delta Cross Channel gates were both open and closed. We identified consistent patterns in survival among migration routes, but substantial variation in survival among releases and years. Specifically, releases in 2008 exhibited lower survival than other years. Despite considerable variation among releases, survival for routes leading to the interior Delta was always lower than for Sacramento River. Fish that migrated through Sutter and Steamboat sloughs had survival probabilities that ranged between that of the Sacramento River and the interior Delta. Because of route-specific differences in survival, the fraction of fish using each migration route will affect population-level survival. The fraction of fish entering each route was generally related to the fraction of discharge, but large deviations from this expected relation suggested other factors also influenced migration routing. We discuss how survival within migration routes interacts with movement among routes to influence population survival. Such insights are critical for quantifying the effect of water management actions on endangered juvenile salmonids.

Sacramento River steelhead trout: Comparing wild and hatchery smolts

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There has been little research on the migratory movements of wild steelhead trout in the Sacramento River. It has been hypothesized that wild smolts will have a higher survival rate and behave differently than hatchery smolts. To examine this question, steelhead trout were surgically implanted with Vemco V7 acoutstic tags. 150 Coleman National Fish Hatchery smolts were tagged and released, with 50 fish released at three locations (Jelly's Ferry RKM 517, Irvine Finch RKM 414, and Butte City RKM 363) during both December 2008 and January 2009. Thus, a total of 300 tagged individuals were released. 60 wild fish were captured in a rotary screw trap and implanted tagged from Mill Creek (RKM 462), a tributary to the mainstem Sacramento River. The purpose of this study was to track the migratory movements and survival of both wild and hatchery smolts throughout the Sacramento River Watershed. Route selection within the Delta and the success rate of fish navigating a particular route are also examined. The majority of steelhead studied—hatchery December (n=30), hatchery January (n=43), and wild (n=21) respectively—utilized the mainstem Sacramento River (63%, 48%, 47%) when moving through the Delta, with a considerable number of individuals using Georgiana Slough (20%, 25%, 28%), and a smaller proportion of fish using Steamboat (7%, 12%, 5%), Sutter (10%, 5%, 19%), and Miner Sloughs (0%, 9%, 0%). Hatchery fish that reached the Golden Gate Bridge had an average migratory time of 20 (13-36) days if they were released in December, 23 (10-57) days if they were released in January, and 12 (10-15) days if they were wild smolts.

Friday, August 7, 2009 - 10:50 AM

OOS 46-9: Movement and mortality patterns of Central Valley juvenile late-fall run Chinook salmon (*Oncorhynchus tshawytscha*), and the environmental factors that shape them

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Background/Question/Methods

Migration is often the most perilous stage of an organism's life. In the case of the declining populations of Chinook salmon (*Oncorhynchus tshawytscha*) in California's Central Valley, juvenile emigration from riverine origins to the ocean is a period of high mortality. Specifically, natural and anthropogenic factors within this system have been known to affect emigrating juveniles (smolts) movement and mortality rates. Knowing which variables influence movement and mortality and to what extent help in understanding how environmental factors shape migratory behavioral ecology. Additionally, in a system shared by four runs of Chinook salmon with different migration strategies and varying abundance over time, this information will provide comparative insight into the evolution and requirements of different migration strategies.

Advances in the miniaturization of acoustic telemetry have allowed the tagging and tracking of juvenile Chinook salmon throughout the Sacramento River watershed to the Pacific Ocean. This was made possible by an array of 330 acoustic monitors placed throughout the watershed, allowing for high spatial resolution movement and mortality estimates. I have tagged and released 200 to 300 late-fall run Central Valley Chinook salmon every year for three years from winter 2006/2007 to winter 2008/2009.

Results/Conclusions

The average movement rate for late-fall run Chinook salmon smolts emigrating through the Sacramento River watershed was 30.4 ± 19.6 $km \times d^{-1}$. Movement rates were relatively faster in the upper Sacramento River than downstream in the Sacramento-San Joaquin Delta and Estuary. Of the fish released near the first barrier to anadromy, 4.3 % successfully made the 500 km migration to the Pacific Ocean, taking an average of 26.8 d. Mortality was about 80 % in the first 150 km of the upper reaches of the Sacramento River, 33 % within the lower 300 km of the river, and 60% in the estuary (85 km).

Preliminary analyses of the effects of environmental variables on movement have shown that the Chinook salmon smolts exhibit strong diel patterns, and that increases in movement rates correlate with increases in pulse flows due to storm events. Preliminary analyses of mortality patterns have shown that the presence of anthropogenic water diversions and dams explain some of the variability in mortality rates.

The knowledge provided by data analyses from this study will elucidate migration dynamics of this ecologically and economically important species. These findings will allow more efficient management of the imperiled fishery, and potentially allow predictive power for future cohorts based on conditions alone.

Deliverables

(1) Ammann, A.J., N.J. Nicholas, and R.B. MacFarlane. 2011. The effects of surgically implanted acoustic tags on laboratory growth, survival and swimming performance of hatchery yearling Chinook salmon. *Env. Biol. Fishes*.

(2) Chapman, E.D., A.R. Hearn, C.J. Michel, A.J. Ammann, S.T. Lindley, M.J. Thomas, M.L. Peterson, G.P. Singer, P.T. Sandstrom, B.R. MacFarlane, and A.P. Klimley. 2011. Diel movements of outmigrating Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*) smolts in the Sacramento/San Joaquin watershed. *Env. Biol. Fishes*.

(3) Del Real, S, M. Workman, and J. Merz. 2011. Migration characteristics of hatchery and natural-origin *Oncorhynchus mykiss* from the lower Mokelumne River, California. *Env. Biol. Fishes* (used CALFED monitor array).

(4) Hayes, S.A., D. Nichole, M Teutschel, C.J. Michel, C. Champagne, P.W. Robinson, M. Fowler, T. Yack, D. Mellinger, S. Simmon, D.P. Costa, R.B. MacFarlane. 2011. Releasing the mooring to 'see' where fish go. *Env. Biol. Fishes* (detected CALFED tagged smolts).

(5) Lindley, S., P. Klimley, B. MacFarlane, and A. Ammann. 2011. Estimating survival and migration rates with ultrasonic tagging. *Env. Biol. Fishes*.

(6) Michel, C.J., A.J. Ammann, E.D. Chapman, P.T. Sandstrom, H.E. Fish, M.J. Thomas, G.P. Singer, S.T. Lindley, A.P. Klimley, R.B. MacFarlane. 2011. The effects of environmental factors on the migratory movement patterns of Sacramento River yearling late-fall run Chinook salmon (*Oncorhynchus tshawytscha*). *Env. Biol. Fishes*.

(7) Perry, R.W., P.L. Brandes, P.T. Sandstrom, A.P. Klimley, A. Ammann, and B.MacFarlane. 2010. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento–San Joaquin River. *North Am. J. Fish. Management*, 30:142–156 (used CLAFED monitor array)

(8) Perry, R.W., P.L. Brandes, J.R. Burau, A.P. Klimley, R.B. MacFarlane, C. Michel, J.R. Skalski. 2011. Sensitivity of population-level survival to migration routes used by juvenile Chinook salmon to negotiate the Sacramento-San Joaquin River Delta. *Env. Biol. Fishes*. (used CALFED monitor array)

(9) Sandstrom, P.T., A.J. Ammann, C. Michel, G. Singer, E.D. Chapman, S. Lindley, R.B. MacFarlane, and A.P. Klimley. 2011. Growth, survival, and tag retention of steelhead trout (*Oncorhynchus mykiss)* and its application to survival estimates and behavioral assessments. *Env. Biol. Fishes*.

(10) Sandstrom, P, T. Keegan, G. Singer 2011. Survival and movement patterns of Central California Coast native steelhead trout (*Oncorhynchus mykiss*) in the Napa River. *Env. Biol. Fishes.*

(11) Singer, G.P., A.R. Hearn, E.D. Chapman, M.L. Peterson, P.E LaCivita, W.N. Brostoff, A. Bremner, and A.P. Klimley. 2011. Interannual variation of reach specific migratory success for Sacramento River hatchery yearling late-fall run Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*). *Env. Biol. Fishes.*

(12) Steel, A.E., P.T. Sandstrom, P.L. Brandes, and A.P. Klimley, 2011. Two roads diverged: migration route selection of juvenile Chinook salmon, and the role of water velocity and individual movement patterns. *Env. Biol. Fishes* (used CALFED tagged smolts).

(13) Zajanc, D., S. Hendrix-Kramer, N. Nur, P.A. Nelson. 2011. Downstream migration of Chinook salmon, *Oncorhynchus tshawytscha*, and steelhead, *Oncorhynchus mykiss*, smolts in the highly modified lower Sacramento River, California, as influenced by habitat features of levee banks. Env. Biol. Fishes (used CALFED tagged smolts)